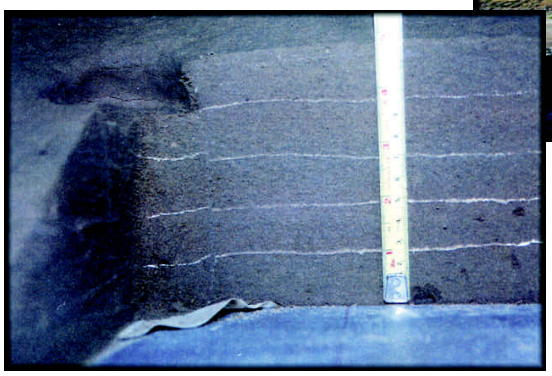
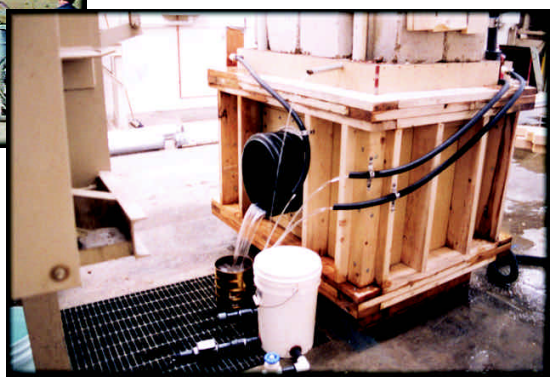
FISCAL YEAR 2001
RESEARCH ACTIVITIES





DAM SAFETY OFFICE
RESEARCH PROGRAM

U. S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

DSO
DAM SAFETY OFFICE

Http://www.usbr.gov/research/dam_safety

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GEOTECHNICAL RESEARCH

FY 2001 Dam Safety Research Proposal

Project Title:

Investigation of Field Quality Parameters for Compaction Grouting

Research Problem and Background:

Compaction grouting is a method for foundation improvement. The design of compaction grouting, estimation of its costs, and quality assurance in the field relies on methods developed with limited case histories, laboratory scale models, and field methods such as CPT and SPT.

It is intuitive that initial soil conditions have a large impact on the success of compaction grouting. Parameters such as grading, fines content, and void ratio need consideration. Methods to account for variations have been suggested. One such method which has emerged is the Grout Index Number which is designed to result in a uniform densification of treated soils. The prediction of an index number could be improved with some key data established in the laboratory, particularly data found with typical soil configurations from our design site.

The method of compaction grouting is performed below ground and results cannot be visually observed. The method remains as much an art as a science and is a viable alternative in a short list of possibilities for in-situ ground improvement. The method is planned for use at Pineview Dam.

Abstract of Objective:

The objective of this research is to develop a limited number of parameters for study in the laboratory to support or improve current information used in the Grout Index Number particularly grout pressure and volume of grout placed. Of particular interest at the Pineview site are widely graded soils, and a complex geometry of soil layers and lenses. This research would establish a baseline test in dry and saturated sand, then simulate more complex soil layering in a step-wise fashion: 2 layers, low density thin layer between 2 layers, other configurations following study of initial results.

Reclamation's review and reporting would focus on improvement of a field tool for use in developing a GIN value for Pineview. This project is suggested as possible candidate project for a research cooperative with a university. The participation would be treated as a part time hire, not as a grant. A graduate student team member would be able to complete extensive review of the state-of-the-practice, perform extensive analysis of the laboratory and field data, and complete a detailed report (thesis) of the effort, and conceptualize additional research needs. This would extend the contribution of the work. As seen in the estimate table this would also add to the costs.

Benefit to DSO:

Verification of compaction grout results in the lab to predict ground improvements for Pineview Dam.

Principal Investigators:

Karen Knight, D-8311; David Harris, D-8180, Kurt von Fay, D-8180, (303) 445-3041, (303) 445-2375, (303) 445-2399

Proposed Team Members:

Kurt Mitchell, student graduate candidate

Proposed Peer Reviewer(s):

John Cyganiewicz, D-8311

Proposed Partners:

Dam Safety Office

Progress to Date:

One demonstration of the use of the 6'x6'x4' soil box used under the 5 million pound machine has been completed to assure viability of the test method. A typical test bulb was completed by Denver Grouting in this test. Interesting pressure data showing the pulse and relaxation of each pumping cycle was recorded. A second demonstration will be performed September 14. Additional instrumentation in the soil mass will be tested in this demo.

Future Projects Where Research May Be Used:

Following the laboratory tests, the next work would follow on a test section in the field at Pineview Dam, and then the final work at Pineview would be completed under separate contract.

FY2001 Dam Safety Research Proposal

Project Title:

Modification of Non-plastic Soils for Erosion Resistance

Research Problem and Background:

The existing embankment and borrow materials for Keechelus Dam have little to no plasticy or erosion resistance. It is desirable to have critical portions of the embankment core be non-erodible. A modified Zone 1 material, named Zone 1B, is proposed as a non-erosive core. It is proposed to mix a variety of concentrations of bentonite, lime, and cement with the potential borrow materials (two soils).

Abstract of Objective (200 words or less):

Three test methods are proposed to measure the amount and reduction of erosion of the virgin and modified soils. Since concerns exist about changes in ductility and volume of the modified soil (is it more likely to crack than the virgin material? will shrinkage be greater) a strength test and length measurements are included in the program. It is hypothesized that the soil will change from a brittle low strength material to a ductile higher strength material.

Principal Investigator:

Mark Pabst, Reclamation (D-8313)

Proposed Team Members:

Zeynep Erdogen, University of Colorado - Denver
Tom Strauss, Reclamation (D-8340)

Proposed Peer Reviewer(s):

Perry Hensley, Reclamation (D-8313)
Clarence Duster, Reclamation (D-8313)

Proposed Partners:

University of Colorado - Denver

Progress to Date:

Test material has been received by Soils Lab

Future Projects Where Research May Be Used:

Keechelus Dam

Dam Safety Research Status Update

Project Title:

Understanding the Becker Penetration Test (BPT)

Research Problem and Background:

In 1986 Becker penetration testing was developed by Seed and Harder to estimate the liquefaction resistance of gravelly soils. Many Reclamation dams are founded on loose gravelly alluviums, where the Standard Penetration Test (SPT) is unreliable for determination of liquefaction resistance. Comparisons were made to Standard Penetration Testing. The BPT suffers from several unknowns, energy, friction, and maximum particle size effects. Energy and Friction data are being improved.

Abstract of Objective:

The SPT has been correlated to relative density of sand in large chamber tests. This data and the case history data of SPT at earthquake sites have given us great confidence in using the SPT for liquefaction evaluation. It is not possible to build a large chamber to test the Becker Drill due to the large size required. In this study we wish to collect BPT and SPT data in natural alluviums, and excavate the alluvium to measure in-place density and particle size data. By collecting this data we can begin to understand particle size effects and increase our confidence in density/liquefaction prediction. Other methods can be used to test gravels, such as Large Penetration Tests (LPT) and Dynamic Cone Penetration Tests (DCPT). There are also questions regarding placement of shear wave velocity holes using the Becker drill because of ground densification. This will be evaluated by comparing shear wave data in becker versus rotary wash installations. We will also collect density and gradation data when dams are modified and as the alluvium is excavated.

Principal Investigator:

Jeffrey A Farrar, D 8340, Earth Sciences Laboratory (445-2333)

Team Members:

Sandy Kunzer, D 8321, Dave Gillette, D 8313, Ira Terry PRO-205, Mike Pryor, PXAO 2200, Brent Carter PN 3200

Peer Reviewer(s):

Karl Dise, D8311, Perry Hensley D8313, Les Harder, CA DWR, Joe Koester, USACE WES, and peer reviewed papers

Proposed Partners:

U S Army Corps Of Engineers, Waterways Experiment Station, Joe Koester (has a funded program). Ken Lum BC Hydro, Alex Sy, Klohn Crippen, Prof. John Howie, University of British Columbia Vancouver.

Progress to Date:

In FY 98 a plan was developed to perform field studies in quarries or at a dam site. The plan calls for 5 Becker holes, 2 SPT holes, 2 LPT holes, 4 DCPT holes, two cross holes shear wave tests, and 20 in-place density tests. In FY 99 we placed a request with regional geologists to search for sites at or near Bureau Dams that could be excavated. Several prospective sites have been identified. In FY 99 we assisted with special friction tests for Becker drilling at Echo Dam.

In FY00 little progress was made due to extremely heavy project workload. Discussions were held with the UC region to perform a comparison study between Standard Penetration Test (SPT) and Large Penetration Test (LPT) at the Point of the Mountain quarry. However, this study was canceled because of last minute need to spend dam safety funds for safety upgrades. This study might start early in FY 01.

Future Projects Where Research May Be Used:

Deer Creek, Pineview, Wanship, Echo, Kechulus, Senator Wash and many others.

Dam Safety Research Status Update

Project Title:

Liquefaction and Non-Liquefaction Case Histories

Research Problem and Background:

Commonly available analytical tools for predicting slope stability and/or deformation are generally effective for demonstrating that an embankment is stable and would undergo only minor deformations (demonstrating the adequacy of a design). However, they are not always effective for predicting the behavior of embankments that are unstable or marginally so. Even the most sophisticated deformation models have severe limitations (including the time and cost of implementation) and are not well verified by field experience. Hence, knowledge gained from case histories of actual dams (and other sites) subjected to strong earthquake loading can be very useful in risk assessments and modification decisions.

Abstract of Objective (200 words or less):

For this project, 15 to 20 case histories will be described and discussed. Each summary will be two to five pages long and will include the earthquake loading, background information on the structure or site, a description of its behavior, and conclusions that can be drawn from it. The case histories include earthquake liquefaction sites (e.g., Sheffield Dam, Lower San Fernando Dam, Kawagishi Cho Building in Niigata), dams that were subjected to earthquakes but did not experience liquefaction (e.g., Austrian Dam, Hebgen Lake, La Villita Dam), fault rupture in a dam foundation (Baldwin Hills Dam), "static" liquefaction (Fort Peck Dam), and seiche-wave overtopping (Hebgen Dam).

Principal Investigator

Dave Gillette, D-8313, (303)445-2994

Team Members:

Karl Dise, D-8311

Peer Reviewer(s):

Geotechnical Engineering group managers

Partners:

Progress to Date:

Good-quality drafts have been prepared for Baihe Dam, Baldwin Hills Dam, Fort Peck Dam, La Marquesa Dam, La Palma Dam, La Villita and Infiernillo Dams, Mochikoshi Tailings Dams, and Sheffield Dam. Progress has been disappointing due to "billable" work (design, CFRs, etc.)

Future Projects Where Research May Be Used:

Risk analyses for modification decisions and comprehensive facility reviews; evaluation of analytical tools.

Dam Safety Research Status Update

Project Title:

Case Histories of Piping and Non-Piping

Research Problem and Background:

A study of case histories of embankment dams can provide factors that, in general, contribute to accidents, to piping failure, and to satisfactory performance of embankment dams. During a risk analysis of a dam, a careful review of a few case histories of similar dams that had accidents or failed can result in insights into possible failure mechanisms. Also, this knowledge can be useful in comprehensive facility reviews and decisions about modifying existing embankment dams.

Abstract of Objective:

The objective is to examine case histories of embankment dams in order to identify factors that contributed to accidents and failure related to piping and erosion. A large data base of case histories has been collected by Professor Robin Fell, from the University of New South Wales, Australia, and is now available for our use. The use of "key words" is being developed to search for case histories of dams that are similar to Reclamation dams and can be used in risk assessment studies.

Principal Investigator:

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Team Members:

Roger Torres, D-8312, with help from Don Serina with Microsoft Access.

Peer Reviewer:

Geotechnical Engineering group managers and John Cyganiewicz

Partners:

N/A

Progress to Date:

The focus of the study has changed somewhat. Initially, about 15 to 20 case histories were to be summarized, including a description of the incident, geology and foundation, dam design and construction, and conclusions. Since Professor Robin Fell's case histories are available to us, the case histories will not be summarized; however, "key words" have been identified to search through the data base. Also, a small library of information related to piping of dams has been collected. Case histories since 1989, including dams having gypsum in their foundations, are being added to the data base.

Future Projects Where Research May Be Used:

In risk analyses, modification designs, and comprehensive facility reviews of existing dams.

Dam Safety Research Status Update

Project Title:

Gradient Ratio Test for Evaluating Toe Drain Performance

Research Problem and Background:

Reclamation toe drain designs typically use perforated HDPE drain pipe with coarse gravel envelope. At Lake Alice Dam, a single-stage sand envelope was used to retain the fine-grained (silty) native soils. The toe drain pipe perforations quickly plugged with the sand particles. Therefore, dams in areas with fine-grained native soils require a 2-stage filter to function adequately. Two-stage filters using geotextiles offer the most promise as the geotextile can simultaneously maximize flow rates, minimize loss of envelope material, and significantly reduce construction costs. Research is needed to develop design guidelines for these two-stage filters.

Abstract of Objective (200 words or less):

Develop a small-scale laboratory test for evaluation of toe drains with various sand and gravel envelopes, geotextile pipe socks, pipe walls (single wall vs. double wall) and perforations (holes vs. slots). Small-scale testing would cost less per test and more economically evaluate toe drain performance than the current full-scale laboratory test. Gradient Ratio (ASTM D-5101) will be used for the small-scale test and modified as appropriate to evaluate flow rates, envelope loss, settlement, and formation of natural soil filter at the pipe/envelope interface. Test parameters will be chosen to duplicate envelope gradations, flows and gradients expected in the field, as well as higher flows and gradients to evaluate worst-case scenarios. Some duplicate tests may be performed by Dr. George Koerner at the Geosynthetics Research Institute (GRI) at Drexel University in their “Long-term Flow Apparatus” for comparison.

Principal Investigator:

Jay Swihart (D-8180) 303-445-2397

Team Members:

Perry Hensley (D-8313)
Glen Sanders (D-8550)

Peer Reviewers:

Dr. Robert Koerner
Geosynthetic Research Institute (GRI)
Drexel University, Philadelphia PA

Partners:

Dr. George Koerner (GRI)

Progress to Date:

DSO has funded previous work to perform full-scale and small-scale laboratory testing on Toe Drains. Previous small-scale testing used the Soils Lab Filter Test Apparatus to evaluate the toe drain installed at Lake Alice Dam. These tests seemed to adequately model field performance in some areas such as clogging of pipe perforations, but were not entirely satisfactory. Therefore a full-scale test apparatus was designed and constructed to more accurately model field conditions. Full-scale tests were

performed on toe drain designs for Lake Alice Dam, Enders Dam, and Many Farms Dam. These tests were quite successful but relatively expensive. A small-scale Gradient Ratio Apparatus has now been purchased for calibration against the previous full-scale tests.

Future Projects for Use:

This research will develop design criteria for single- and two-stage filters using sand, gravel and geotextiles. Once developed, this test will be available for a quick and cost-effective evaluation of toe drain construction on all Bureau projects.

Dam Safety Research Status Update

Project Title:

Resistance of Soils to Piping

Research Problem and Background:
Most Reclamation embankment dams were not constructed with state-of-the-art designed filter zones to help preclude failure by internal erosion. Risk analyses of this issue usually focus on the zones downstream of the core and assess their capability to filter the core. Sometimes these zones meet current filter criteria, but most other times they don't. It might be possible to evaluate those risks using a supplemental criteria that can provide additional information on the potential effectiveness of the downstream zone in providing filter protection for the dam's core.

Abstract of Objective (200 words or less):

The University of New South Wales has developed a new supplemental criteria to evaluate filters in a existing dams . Building upon the Sherard and Dunnigan work in 1989. on the NEF test, UNSW has extended the test to to include a parameter "Continuing Erosion". Existing dams may have filters that do not meet current NEF filter criteria, however the filters still may perform adequately by sealing after "some" erosion of the base material into the filter. The continuing erosion boundary has been roughly established by the University of New South Wales using eight samples of varying classifications. The purpose of this project is to build on UNSW's data that establishes limits for continuing erosion and also to verify the reliability and reproducibility of their test procedure.

Principal Investigator:

Nathan Snorteland

Team Members:

Jeff Farrar

Peer Reviewer(s):

John Cyganiewicz

Partners:

University of New South Wales
Possibly a private testing laboratory

Progress to Date:

Reclamation partially funded UNSW's research into erosion studies. The establishment of the continuing erosion boundary is a product of that research.

Future Projects Where Research May Be Used:

Embankment Dams that do not meet state-of-the-art filter criterion.

CONCRETE RESEARCH

FY2001 Dam Safety Research Proposal

Project Title:

Drillhole Parameter Recorder Used to Find Concrete Properties and Features

Research Problem and Background:

The Drillhole Parameter Recorder (DPR) has been used extensively in Europe with success to find soil properties real time while drilling. Research Report R-99-09 - An Investigation of Drill Parameter Recorders and Their Use with Concrete Drilling Programs reports: “Case studies indicate they have been successfully used to classify soil lithology, locate voids, and define grouting needs. ... Several researchers have correlated DPR data to known material properties of compressive strength and the Standard Penetration Test.”

Abstract of Objective (200 words or less):

From R-99-09, Establish a procedure to correlate DPR while coring concrete to laboratory test results. Once established, DPR results taken during drilling can be used to provide a continuous assessment of spatial properties between core tests taken at discrete locations. This method has advantages in that irregularity in a drillhole, and the need to establish instrument contact to take readings is eliminated; and that the correlations are based on measurements of mechanical parameters such as torque and crowd which are much more akin to physical testing methods than other downhole methods. Once the correlation is complete, parameters such as strength can be referenced throughout the entire drillhole.

Principal Investigator:

Jeff Farrar or David Harris

Proposed Team Members:

Larry Nuss, Greg Day

Proposed Peer Reviewer(s):

Chuck Redlinger

Proposed Partners:

Regional Drill Crew
Dr. Benoit

Progress to Date:

An existing DPR system has been tested at Horsetooth Dam. Case histories report R99-09 has been prepared.

Future Projects Where Research May Be Used:

Pueblo (maybe)
Upcoming Dam safety core recovery project

Dam Safety Research Status Update

Project Title:

Failure Modes of Arch Dams - Large Shake Table and Nonlinear Analysis

Research Problem and Background:

The risks associated with seismic analysis of concrete dams in many cases have been estimated to be quite high. This is based largely on evaluation results from linear-elastic continuum finite element analyses. No concrete dams are known to have failed during an earthquake, and cases of concrete dams subjected to large earthquake shaking with good records of the response are extremely limited. Some cracks have been reported, such as Pacoima Dam where the dam and abutment separated during the Northridge earthquake, but the reservoir was down at the time of the event. Therefore, it is not clear exactly how a concrete dam, particularly an arch dam, might fail during an earthquake, and it is not clear how well our analytical models predict structural performance during very large levels of shaking. Initial studies have been done using 2-D shake table tests and analytical modeling of a model in the shape of a Koyna Dam (India) monolith, but without the reservoir.

Abstract of Objective (200 words or less):

Large laboratory shake table tests of a representative arch dam and reservoir will be performed, ramping the loading up to failure of the model. Models fairly correct as to similitude modeling will be used, including a reservoir behind the scaled structure. Input motions and structural response will be measured, and high quality video will capture the failure modes. Lawrence Livermore National Laboratory has offered the use of their digital laser imaging system if we pay for their operator. Several variations will be tested including a monolithic model, models containing vertical contraction joints, models containing horizontal joints to represent weak lift lines, and models containing both vertical and horizontal joints. The models will be analyzed using the ABAQUS finite element computer code to determine how accurately the response can be modeled and the failure predicted. This will help calibrate and validate the use of these computer analyses for estimating failure likelihoods.

Principal Investigator:

Terry Payne, Reclamation (D-8110)

Team Members:

David Harris, Reclamation (D-8160), Roman Koltuniuk, Reclamation (D-8110)

Peer Reviewer(s):

Gregg Scott, Reclamation (D-8110) and Larry Nuss, Reclamation (D-8110)

Partners:

None.

Progress to Date:

Nine 1:150 scale arch dam models have been assembled and tested on the large shake table in Reclamation's research laboratory. Four of the laboratory models were monolithic. Three of the laboratory models included a single vertical contraction joint. Two of the laboratory models included a single horizontal joint(disbonded lift line). A 14 hertz sinusoidal input motion was applied to each of these models. The amplitude of the input motion was increased in one quarter g increments until failure

of the arch dam model occurred. The failure modes have been recorded on video tape. Displacements and accelerations at several locations on the models were recorded and are available for comparison with numerical analyses.
Three finite element models have been created using both SAPCORD and ABAQUS-PRE. One of the finite element model is monolithic, one includes a single vertical joint, and one includes a single horizontal joint. The laser imaging system has not been used to date.

In order to fully assess the potential behavior, additional shake table models and corresponding ABAQUS models with 17 vertical contraction joints, and 17 vertical contraction joints with two horizontal joints are required.

Future Projects Where Research May Be Used:

Nearly every risk analysis of a concrete arch dam requires some estimate of failure likelihood under seismic loading. This research should help individuals and teams in interpreting the results of analytical modeling as it relates to failure potential.

Remaining work for FY 2000:

Additional shake table tests of an arch dam with two horizontal joints will be performed this Fiscal Year (FY 2000) Analytical models with 2 horizontal joints, 17 vertical contraction joints, and 17 vertical contraction joints with two horizontal joints will be created. The remaining testing and modeling will be accomplished in FY 2001. The reports will be prepared in late FY 2001 or possibly early FY 2002.

Dam Safety Research Status Update

Project Title:

Kinematic 2-D block sliding - Small Shake Table and Nonlinear Analysis

Research Problem and Background:

Concrete Dams and Foundation Rock. Addresses uncertainty UA2.

Abstract of Objective:

Ultimate failure of concrete dams or jointed rock foundations is from rigid body movements of independent blocks sliding along surfaces. This rigid body failure depends on the contact behavior of the block and surrounding surfaces and on the seismic forcing function imposed on the structure. Accurately understanding and modeling this mode of failure using analysis tools and shake table facilities will greatly improve the understanding of failure potential, and consequently risk analyses for concrete dams and their foundations. Additionally, the hypothesis that "precariously balanced" rocks can provide paleoseismic constraints on probabilistic estimates of peak ground motions is in question and is an extension of the proposed study. This hypothesis could be rigorously evaluated using the shaking table and ABAQUS simulation results.

The nonlinear behavior of portions of structures which form independent blocks /contact surfaces subjected to earthquake ground motions has, to date, been modeled using the computer code ABAQUS. However, the accuracy of these ABAQUS simulations of the dynamic responses has not been verified for complex geometries. This project will use a small Reclamation shaking table to subject simple block configurations to high and low frequency sine waves and to recorded earthquake motions. The ability of ABAQUS to realistically simulate block sliding and toppling behavior for stacks of one to three blocks and for a range of block height-to-width aspect ratios will be evaluated. The effect of offset center of gravity will also be studied. This research will provide Reclamation with a proven tool to evaluate the nonlinear behavior of concrete dams and general block structures. This project will substantially improve Reclamation's structural analysis capabilities and provide a validated approach to assess the value of "precariously balanced" rocks in probabilistic seismic hazard assessment.

Principal Investigator(s), Team Member(s), and Peer Reviewer(s):

Staff:	Barbara Mills-Bria	Larry K. Nuss	Gregg Scott (Peer)	Dave Harris
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Progress to Date:

In FY2000, this project was funded and started. The small shake table is being built. Procurement of the actuator on the shake table has caused delays, so the table could not be completed in FY2000. Therefore, funding for the shake table tests and analyses for this project will be moved to FY2001.

In FY1999, a comprehensive evaluation of previous research in the theory of block stability, the use of shaking tables in block stability research, and the performance of ABAQUS in simulating two-dimensional dynamic block responses to steady-state shaking has been completed and a report filed with Dam Safety ("Verification of Block Kinematic Response as Calculated by ABAQUS", DSO-98-009). A suite earthquake ground motions has been assembled. The "precariously balanced" rocks literature has been assembled and reviewed. The resonances of Reclamation's shaking table have been determined and are confined to frequencies higher than will be needed for the planned experiments. The

laboratory also has the capabilities to use a smaller shake table configuration.

Future Projects Where Research May Be Used:

1) All of Reclamation's concrete dams and appurtenant structures; 2) development of probabilistic seismic hazard assessments for Reclamation dams; 3) comparison with geotechnical tools which model block behavior in dam foundations.

Schedule and Partnership Contributions (All Years):

Schedule: The schedule is to complete the project in FY2001 and to submit two papers for publication in engineering and earthquake journals.

Dam Safety Research Status Update

Project Title:

Dam Drainage Manual

Research Problem and Background:

This work consists of developing a manual for the design/analysis, installation, and maintenance of drains associated with dams.

Abstract of Objective (200 words or less):

The manual will consist of the following chapters: Chapter 1 - Introduction, Chapter 2 - Background, Chapter 3 - Drain Design and Analysis, Chapter 4 - Drain Installation, Chapter 5 - Drain Performance (Case Histories), Chapter 6 - Monitoring and Maintaining Drains, Appendix A - Design Examples, Appendix B - Detailed Case Histories, Appendix C - Drain Inspection/Cleaning Equipment. Chapters 5 and 6 are the key chapters in the manual as they provide guidance for maintaining drains. The other chapters provide background on drains and how they affect the stability of structures.

Principal Investigator:

Bill Fiedler

Team Members:

Bill Fiedler, John LaBoon, D-8130; Rich Munoz, D-8110; Lonnie Lewis, D-8250; Steve Young, D-8311; Becky Morfitt, D-8312; Gary Turlington, D-8322; Rick Kelsic, D-8460.

Peer Reviewer(s):

Gregg Scott, Larry Nuss, D-8110; two peer reviewers from the Geotechnical Groups are also anticipated.

Progress to Date:

A complete draft of the manual that has been reviewed internally by the manual team and by Lonnie Lewis (technical editor) will be completed by the end of the fiscal year.

Future Projects Where Research May Be Used:

This manual will have application at most Reclamation Dams since most Reclamation dams have some type of drainage system.

Dam Safety Research Status Update

Project Title:

Seismic Tomography on Concrete Dams

Research Problem and Background:

The seismic tomography method has been used to evaluate the condition of concrete, masonry, and embankment dams for several years by other groups, most notably in Italy. Reclamation has applied cross-borehole seismic tomography to a few dam safety problems, in embankments and within a masonry dam. Reclamation traditionally has not performed seismic tomography surveys on concrete dams, mainly because of the lack of equipment necessary to acquire large amounts of high-quality, high-frequency seismic data in an efficient manner on a concrete dam without drilling boreholes. This research project addresses this need.

Abstract of Objective:

The main objective of this project is to develop and evaluate Reclamation's capabilities to perform efficient, high-quality seismic tomography surveys on concrete dams for the purpose of imaging variations in concrete properties. To obtain this objective, various types of field equipment must be evaluated to determine the optimum equipment to use, field equipment must be purchased and constructed, and software must be modified. Forward modeling should be performed to determine the best data acquisition parameters. A full scale field test will then be performed to test the equipment and data processing procedures and to evaluate the usefulness of the seismic tomography method for imaging variations in concrete properties. The reliability of the tomography results will be evaluated by comparing the results from the seismic tomography survey to results obtained from geophysical borehole logging and/or coring.

The project has been divided into 4 phases:

- Phase I: Preliminary equipment tests
- Phase II: Preparation for field work
  - a. Purchase and construct field equipment
  - b. Modify tomography data processing software.
  - c. Do forward (computer) modeling.
- Phase III: Field work and preliminary on-site data processing.
- Phase IV: Final data analysis and report preparation

Principal Investigator:

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Team Members:

Lisa Block, Jim Jones, Steve Lux, Dan Mares

Peer Reviewer(s):

Larry Nuss, Jerry Wright

Proposed Partners:

possibly the Canadian Electric Association

Progress to Date:

Phase I, consisting of preliminary equipment tests, was completed in FY97. A report on the testing procedures and results from Phase I was finalized in February, 1998. The report was published by the Dam Safety Office in September, 1998 [1].

Phase II, involving hardware and software development, was completed in FY98 and FY99. During Phase II, field equipment needed for acquiring high-quality seismic tomography data in an efficient manner was purchased and/or constructed. This equipment includes a 20-channel, high-speed data acquisition system, a 16-receiver hydrophone string, 16 high-frequency accelerometers, amplifiers and power supplies for the accelerometers, and two power-actuated fastening tools, slightly modified to be used as repeatable, high-frequency seismic sources on the surfaces of a dam. Some computer modeling was also done during Phase II. A program was developed that allows the user to interactively design an acquisition geometry and then examine images indicating how much seismic ray coverage each part of the dam receives for that geometry. The data acquisition geometry for the field work at Seminoe Dam was developed with this software. Also, processing software for plotting the seismic data and determining arrival times and amplitudes was extensively modified.

Phase III, field testing at Seminoe Dam, was initially performed in April, 1999. Analysis of the initial data set indicated that more accurate triggering was required, as well as more detailed surveying of the dam face for control of the geometry. Two new methods of triggering were developed, and additional data were acquired along the same cross section in late September, 1999. The downstream dam face was also surveyed at that time, using a total station surveying instrument. A velocity tomogram of a vertical cross section through Seminoe Dam was computed from the seismic data acquired in 1999. This image, as well as a comparison to reservoir levels and mapped fracture locations, was transmitted to the Dam Safety Office in March, 2000 [2]. In August, 2000, seismic data were acquired along 2 additional vertical cross sections of Seminoe Dam. Travel times from these data are currently being analyzed.

Future Projects Where Research May Be Used:

Any concrete dam for which the variations in concrete properties or extent of deterioration needs to be evaluated.

References:

[1] Seismic Tomography of Concrete Structures, Phase I: Equipment Tests; Dam Safety Office Report No. DSO-98-002; Bureau of Reclamation; September, 1998.

[2] Bureau of Reclamation Memorandum: Seismic Tomography Results from Seminoe Dam; sent to Chuck Redlinger, Dam Safety Office (D-6600); March 7, 2000.

HYDROLOGY AND PALEOHYDROLOGY RESEARCH

Dam Safety Research Status Update

Project Title:

Flood Hydrology Database

Research Problem and Background:

The physical understanding and modeling of extreme flood events requires collection and review of a variety of flood hydrology data including, but not limited to: available modeling methods, peak discharge and mean daily streamflow records, precipitation data (rainfall and snowfall), temperature data, soil data, paleo data, weather pattern analyses, etc. A searchable database that includes organized and connected lists of the various available data, visual selection capability, and hotlinks to the data would allow for faster and more through assessment of study options.

Abstract of Objective:

This project focuses on developing a flood hydrology database that identifies, summarizes and is linked to hydrologic data that is useful for developing flood frequency analyses, collecting and assessing input for stochastic rainfall-runoff models, and for performing other flood hydrology studies. Data retrieved from the database will be used in various models to make statements about flood hazard probability for use in risk analyses. The eventual goal of this project is to provide spatial and temporal views of the 17 western states for data availability used in probabilistic flood hazard studies. This project was intended to be an ongoing study that would be reviewed on an annual basis.

Principal Investigator:

Karen Weghorst

Team Members:

n/a

Peer Reviewer(s):

n/a

Partners:

n/a

Progress to Date:

An ARCVIEW project file has been assembled that includes a BOR dam database (entire U.S.), hydrologic unit polygons and data files (entire U.S.), river shape and data files (entire U.S.), and a detailed color relief map of the U.S. A sampling of data specific to the Sierra Nevada region and parts of northern California have been tabulated but not yet incorporated into the project file due to the anticipated conversion of the data tables to Access 2000.

Future Projects Where Research May Be Used:

All existing dams and other projects that are being assessed for hydrologic analyses.

Dam Safety Research Status Update

Project Title:

MGS Model Refinements

Research Problem and Background

The development of the MGS Consultants stochastic rainfall-runoff model was funded by the Reclamation Dam Safety Office with the intention that the model could be used for flood hazard estimation. However, significant questions have been raised regarding the model and the model documentation. The purpose of the research project is to try to address these issues.

Abstract of Objective

This project is directed at making key refinements to the MGS Stochastic Model that has been previously used by Reclamation on several projects. An important aspect of the model refinements will be the development of methodologies to estimate confidence intervals for model output, better incorporate model parameter uncertainty, allow for the incorporation of paleoflood data, and explore the feasibility of expanding event simulations to eliminate the piecewise construction of the frequency curve.

Principal Investigators:

Marijo Camrud

Team Members:

Mel Schaffer, MGS Consultants, Ed Tomlinson, Applied Weather Associates

Peer Reviewer(s):

John England, Dan Levish

Partners:

N/A

Progress to Date

MGS consultants has submitted the first two deliverables. They are currently in review. The contract has been awarded to Applied Weather Associates for the extreme storm study of eastern Oregon.

Future Projects Where Research May Be Used

After additional refinements, it may be possible to use the MGS model to provide volume estimates for flood hazard analyses. This use will depend on proper calibration. The Applied Weather Associates study will be the first of its kind for Reclamation. It will provide an independent check on the results of the MGS study for A.R. Bowman Dam and may provide the prototype for other extreme storm studies for Reclamation flood hazard analyses.

Dam Safety Research Status Update

Project Title:

Development of a Paleoflood Database for Rivers in the Western U.S.

Research Problem and Background

Paleoflood data requirements are needed to support the development of hydrologic loads for input into risk assessment and flood hazard studies. In addition to collecting reconnaissance-level data to be used in CFR-level flood frequency analyses and evaluating extreme flood events, the focus of this year's research was to develop a repository for this information that could be used in support of probabilistic flood loads for Reclamation dams in the western U.S.

Abstract of Objective

Develop a paleoflood database for the Western United States to provide background data in support of CFR-level flood frequency analyses and flood hazard studies. In addition, information on the magnitude and frequency of large historic floods will be compiled to compare with paleoflood records and put regional envelope curves into a probability context. Site specific studies will be undertaken to develop detailed information at selected locations. These locations will be guided by the results of an evaluation of the Reclamation dam portfolio by the Flood Cadre (under WOID EFLCP). Work will continue on the tool development and evaluation of paleoflood methodologies and their application to flood hazard studies and dam safety assessment.

Principal Investigators:

Ralph Klinger and Jeanne Klawon

Team Members:

Dan Levish, Dean Ostenaa, and Dan O'Connell

Peer Reviewer(s):

Dan Levish, P. Kyle House (University of Nevada); Katie Hirschboeck (University of Arizona)

Partners:

Dr. Katie Hirschboeck, University of Arizona; Dr. P. Kyle House and Michael Kellogg, Nevada Bureau of Mines and Geology

Progress to Date

Reconnaissance-level paleoflood data was collected at 12 field sites this year and applied to 11 CFR-level flood frequency analyses (listed at the end of this update). A repository for these data was developed by Dr. Katie Hirschboeck at the University of Arizona utilizing Microsoft Access software. This database is currently being tested. A copy of the final report describing last year's progress is attached and a copy of the database in its current configuration can be downloaded from the internet at the URL:

http://tree.ltrr.arizona.edu/~katie/kt/USBR/paleoflood2000.mdb.

The Bureau of Reclamation and the Probabilistic Flood Hazard Cadre partially supported the 2nd International Paleoflood Conference, an interagency collaboration, on September 26-October 1, 1999, in Prescott, Arizona. Ten papers were presented at this conference by either Reclamation or Reclamation-

supported collaborators. Some of these papers will be published in a special volume by the American Geophysical Union early next year (Spring 2001) and include a comparison of differing paleoflood methodologies used on the Verde River in Arizona; the reassessment of a large historical flood in El Dorado Canyon in Nevada; and a presentation of the paleostage nonexceedance method used in paleoflood studies.

A paleoflood study on the Carson River in Nevada by Michael Kellogg and P. Kyle House at the University of Nevada was initiated last year. Progress on the study included the selection of three field sites, the Brunswick Canyon, Eureka Canyon, and Markleeville sites. Preliminary results of study at these three sites suggest that there has been less than four floods of magnitude comparable to the 1997 flood in the last 10,000 years on the Carson River. Estimates for peak discharge of non-exceedance bounds preserved at two of the sites were made. The magnitude of these discharge estimates are on the order of about 120% to 230% of the 1997 flood, which is the largest flood in the historical record at the Markleeville site. Age estimates for the non-exceedance bounds are pending. A copy of the progress report prepared by Michael Kellogg is attached.

Non-labor funding was also used in support of the paleoflood data collection activities, continuing studies of paleoflood methodologies and tool development, and a variety of specialized laboratory costs including paleobotanical identification, soil and radiocarbon analyses.

Future Projects Where Research May Be Used

Products of this research provide a resource for regional paleoflood data and an evaluation of extreme flood events in the western U.S. that can be utilized in developing probabilistic flood loads for dams in the Great Plains, Mid-Pacific, Pacific Northwest, Lower Colorado, and Upper Colorado regions. Publication of research on paleoflood methodologies and the results of specific paleoflood study results in widely circulated peer-reviewed literature will promote Reclamation programs in the probabilistic flood hazard and risk assessment arena.

Schedule for the Upcoming Fiscal Year

Continued data acquisition for Reclamation paleoflood database	Begin early in FY2001
Development of user interface for paleoflood database	November 2001
Final Report Slackwater/Non-Exceedance Comparison	November 2001
Complete testing of paleoflood database	April 2001
Reconnaissance for extreme peaks evaluation	June 2001
Reconnaissance for erosion/deposition processes studies	June 2001
Preliminary report for extreme peaks evaluation	September 2001
Preliminary report for erosion/deposition processes studies	September 2001
Final Report on Carson River	September 2001
Summary Document for Paleoflood Database	September 2001

Schedule and Partnership Contributions to Date (All Years)

The goal of developing a searchable computer database was completed through collaborative efforts with Dr. Katie Hirschboeck and her students at the University of Arizona. The initial phase of the database development was completed on schedule, within the allotted budget, and is currently ready for the testing phase. A copy of the final report summarizing last year's progress is included (attachment) and a copy of the database in its current configuration can be downloaded from:

http://tree.ltrr.arizona.edu/~katie/kt/USBR/paleo2000.mdb.

The final reports documenting the reevaluation of an extreme historical flood at El Dorado Canyon in Nevada, and the results of studies on the Verde River in Arizona are currently in review for a American

Geophysical Union special publication due for release early next spring.

Preliminary work on the paleoflood history on the Carson River in Nevada has begun. This work is being undertaken by Michael Kellogg and P. Kyle House at the University of Nevada. A preliminary report summarizing work to date was submitted on schedule (attachment). Costs associated with this aspect of the project included funding for field data collection and laboratory analyses to constrain age estimates of specific paleofloods, and non-exceedance bounds.

List of CFR Flood Frequency Reports Completed in FY00 with Paleoflood Data Acquired under PALED

1. Preliminary Hydrologic Loadings for Comprehensive Facility Review, Bully Creek Dam, South Dakota, prepared by Jo Camrud and Ralph E. Klinger, November 1999.

2. Preliminary Hydrologic Loadings for Comprehensive Facility Review, Nelson Dikes, Montana, prepared by Jo Camrud and Ralph E. Klinger, November 1999.

3. Preliminary Hydrologic Loadings for Comprehensive Facility Review, Elephant Butte and Caballo Dams, New Mexico, prepared by Karen M. Weghorst and Ralph E. Klinger, December 1999.

4. Preliminary Hydrologic Loadings for Comprehensive Facility Review, Hungry Horse Dam, Montana, prepared by John F. England, Jr., and Ralph E. Klinger, January 2000.

5. Preliminary Hydrologic Loadings for Comprehensive Facility Review, Como Dam, Montana, prepared by Karen M. Weghorst and Ralph E. Klinger, February 2000.

6. Preliminary Hydrologic Loadings for Comprehensive Facility Review, Angostura Dam, South Dakota, prepared by Jo Camrud and Ralph E. Klinger, March 2000.

7. Preliminary Hydrologic Loadings for Comprehensive Facility Review, Medicine Creek Dam, Nebraska, prepared by Lex Kamstra and Ralph E. Klinger, April 2000.

8. Preliminary Hydrologic Loadings for Comprehensive Facility Review, Mann Creek Dam, Idaho, prepared by Monica Norval and Ralph E. Klinger, May 2000.

9. Flood Peak Discharge and Hydrograph Analyses, Red Willow Dam, Nebraska, prepared by Jo Camrud and Ralph E. Klinger, July 2000.

10. Preliminary Hydrologic Loadings for Comprehensive Facility Review, Owyhee Dam, Oregon, prepared by Lex Kamstra and Ralph E. Klinger, August 2000.

11. Flood Peak Discharge and Hydrograph Analyses, Red Willow Dam, Nebraska, prepared by Jo Camrud and Ralph E. Klinger, July 2000.

Dam Safety Research Status Update

Project Title:

Probabilistic Hydrographs

Research Problem and Background:

Paleohydrologic bounds provide probabilistic estimates of peak hydrograph amplitudes, but not hydrographs for reservoir routing. The focus of this year's research is to develop probabilistic hydrographs suitable for use in risk analyses, and to improve and formalize methods completed during FY00.

Abstract of Objective:

Paleohydrologic bounds provide probabilistic estimates of peak hydrograph amplitudes. The focus of this research last year was to develop probabilistic hydrographs suitable for use in risk analyses, by developing and testing two approaches: (1) combine paleohydrologic bound information with empirical and theoretical two-dimensional (2D) routing methods; and (2) utilize observed hydrographs, daily flow time series and climatology in statistical models subject to paleohydrologic constraints. This year's research will focus on synthetic hydrograph generation and integration with stochastic rainfall modeling. The hydrograph scaling approach developed under FY00 will be formalized. Work under this WOID will be to develop stochastic rainfall inputs and a stochastic rainfall-runoff model that is based on transfer functions derived from hydraulic modeling. Synthetic hydrograph information will be simplified into time-dependent storage/routing parameters in the stochastic model, as derived from hydraulic modeling under WOID PHYLM. A stochastic storm transposition rainfall model will be developed to provide extreme storm input to generate hydrographs. The AR Bowman watershed will be the test bed for storm modeling, synthetic hydrograph creation and probabilistic hydrograph generation. The work under this research plan is highly dependent on, and will be integrated with the hydraulic modeling research (PHYLM).

Principal Investigator:

John England, D-8530, 303-445-2541

Team Members:

Dan O'Connell

Peer Reviewer(s):

Marijo Camrud, Dr. Manu Lall, Dr. George Kuczera

Partners:

Dr. Manu Lall, International Research Institute for Climate Prediction, Columbia University; and Dr. George Kuczera, Department of Civil, Environmental and Surveying Engineering, University of Newcastle, Australia.

Progress to Date:

Consultation with leading hydrologists retained by the PHYPL project in FY00 suggests that the most effective means to calculate probabilistic hydrographs for return periods of at least 10,000 years is to combine realistic synthetic hydrograph information with stochastic rainfall approaches. Several key tasks, essential for creating a capability to compute synthetic hydrographs, were completed under the

FY00 PLHYM project and are listed under the update for that WOID. Progress on the statistical characteristics and observed hydrograph scaling are:

1. Completed literature review of recent statistical methods in flood hydrology, water resources, and statistics applicable to flood frequency, volume and duration, and hydrographs.

2. Identified three conceptual statistical approaches to estimating probabilistic hydrographs: bivariate or multivariate (peak, volume and duration) frequency analysis; peak or volume scaling using simple ratios; and using simple or multiscaling distribution theories. Outlined a simple approach using a rainfall-runoff model.

3. Completed rough sketch of methods to develop simple probabilistic hydrographs for Level II studies that use preliminary (CFR-level) data, as identified by the Flood Cadre.

4. Outlined general method using simple scaling ratios for detailed paleoflood studies. This method completely relies on a peak discharge frequency curve that is based on detailed paleoflood studies and rigorously portrays data and model uncertainties (using FLDFRQ3).

5. Tested and applied the Level II simple hydrograph scaling approach, using CFR-level data, was performed for Red Willow Dam.

6. Applied the peak discharge-volume hydrograph scaling relationships to the North Platte flood study.

Work for FY 01 includes:

1. Formalizing the approach used for the North Platte and Red Willow for application to other sites, and completing documentation.

2. Development of a stochastic storm transposition rainfall model.

3. Development of a stochastic rainfall-runoff model that utilizes the stochastic storm model and transfer functions derived as part of PHYLM research. The model will include uncertainty and be hooked into Dr. George Kuczera's NLFIT calibration package.

4. Test various assumptions, including the scaling invariance hypothesis for distribution scaling. Apply the model to the AR Bowman watershed.

Future Projects Where Research May Be Used:

Any dams that require flood-frequency analyses for return periods exceeding 1,000 years.

Schedule for the Upcoming Fiscal Year:

FY01

Qtr 1. Formalize and document approaches used for North Platte and Red Willow for transfer to other sites. (5 days)

Review stochastic storm transposition techniques. Incorporate orography and spatial distribution aspects. Develop stochastic storm model for Reclamation watersheds. (20 days)

Qtr 2/Qtr 3. Develop stochastic rainfall-runoff model and integrate with NLFIT (15 days).

Qtr 4. Testing on AR Bowman watershed and integration with functions from PHYLM. Project

documentation and manuscript: (10 days)

Schedule and Partnership Contributions to Date (All Years):

During FY00 Dr. Manu Lall suggested improvements to the hydrograph sampling scheme and the addition of uncertainty. Dr. George Kuczera provided recommendations to separate out distributions based on flow mechanism, add in uncertainty and reservoir features using total probability, and develop a stochastic storm model. Other suggestions by Dr. Kuczera are being investigated under PHYLM, including deriving transfer functions for hydrographs based on reservoir storage and attenuation, using 2D models. Most of these costs were recouped under the workshop research (PRCBF) and as part of North Platte reviews (NPRPS).

The status report for the FY00 PLHYM project summarizes other partnership contributions relevant to the PHYPL project.

Dam Safety Research Status Update

Project Title:

Improved Hydraulic Modeling Tools for Paleoflood Analyses

Research Problem and Background:

The problem is to develop robust and accurate modeling tools to convert paleostage observations into discharge estimates to be used in flood-frequency analyses for Reclamation dams.

Abstract of Objective:

Palestage bounds provide direct observation of maximum river stage over thousands of years. The objective of this project is to develop a robust and accurate procedure for converting stage to discharge estimates for meandering river channels, with complicated geometries and transcritical flows. The TrimR2D two-dimensional (2D) steady-state river hydraulics software package was installed at Reclamation in FY00 to estimate steady-state stage-discharge and 2D velocities for paleoflood scale study reaches as part of the FY00 PLHYM research program. TrimR2D works well for discharges with Froude numbers < 0.9, but stage oscillations become pronounced for cases approaching transcritical flow adjacent to eddies. Unfortunately, many optimal paleoflood field sites are located in proximity to these conditions, so improvements to TrimR2D are needed to eliminate spurious stage oscillations to provide accurate discharge estimates.

Principal Investigator:

Dan O'Connell

Team Members:

John England, Dan Levish, and Dean Ostenaa

Peer Reviewer(s):

John England

Partners:

Dr. Roy Walters, National Institute for Water and Atmospheric Research Lmt. (NIWA), Christchurch, New Zealand. Dr. Roger Denlinger, USGS, Vancouver, Washington.

Progress to Date:

D-8330 purchased a TrimR2D source code license and 9 runtime licences from Ocean/River Modeling using D-8330 TSC capitalized equipment funds. A processing flow was created using IDL (Interactive Display Language, which is installed on D-8330 computers) to interactively edit and convert Intergraph-generated terrain models into computational grids for TrimR2D. IDL models were written to digitize wetting and discharge input positions for input into TrimR2D 2D grid. IDL modules were written to post-process the TrimR2D output to produce water depth, velocity, power, and Froude number outputs superimposed on terrain for interpretation of paleostage observations from field sites. The TrimR2D source code was modified to incorporate database information into output files. Dr. Denlinger completed a 2D explicit finite-volume flow program to post-process TrimR2D output. The finite-volume program has been verified to be accurate for transcritical flow. The TrimR2D output is polished with the finite-volume program to improve velocity estimates, water depths, and eddy details. The resulting IDL and TrimR2D software were used in 2D hydraulic modeling for the Folsom, Lost Creek, AR Bowman, North Platte,

INEEL, Verde River, and Cantua Stream Group paleoflood studies. The finite-volume 2D software was essential to complete the Folsom Dam paleoflood hydraulic modeling for several reaches that experience transcritical flow near paleoflood study sites. Validation testing has been performed using high-water mark data from the Verde River combined with current meter information for a ~ 110,000 cfs flood in February 1993.

The FY01 tasks are to improve the wet/dry boundary condition performance for the finite-volume software and improvements in TrimR2D to reduce artifacts and to integrate the changes into the processing software. Finally, the SISL3D three-dimensional (3D) finite-element code will also be installed on Reclamation computers to provide a hydraulic modeling tool for highly-complex channel geometries. The modifications to TrimR2D, SISL3D, and the finite-volume software are being performed using PHYPL FY00 funds in a contract modification to the USGS interagency agreement and a Woodward-Clyde delivery order. Tasks to be accomplished under these agreements include:

Task 1. Software modifications to model TrimR2D to improve speed and accuracy.
- 1.1. Adapt Preconditioned BCG solver to reduce iteration count.
- 1.2. Remove 2dt waves generated by grid resonance.
- 1.3. Explore combination semi-Lagrange/Riemann solver.

Task 2. Software modifications to model SISL3D to improve speed and accuracy.
- 2.1. Convert to allocated memory.
- 2.2. Improve accuracy of Lagrangian trajectory calculations.
- 2.3. Develop unstructured grid generation for rivers.

Task 3. Test and comparison studies.
- 3.1. Regular channel tests: time-dependent input and sloping bottom.
- 3.2. Spillway test: Critical flow.
- 3.3. Converging channel: Critical flow transition and wave propagation.
- 3.4. Constrictions: Flow through partial and full slots.

Several publications were produced related to the FY00 PLHYM project:

Casulli, V., and Walters, R.A., 2000. An unstructured grid, three-dimensional model based on the shallow water equations, International Journal for Numerical Methods in Fluids, v. 32, p. 331-348.

Denlinger, R.P., O'Connell, D.R.H., and House, P.K., in press. An assessment of a depth-averaged flow model over complex three-dimensional terrain, American Geophysical Union Monograph on Paleoflood Hydrology.

Denlinger, R.P., and Iverson R.M., in press. Flow of variably fluidized granular masses across 3-D terrain: 2. Numerical predictions and experimental tests, Journal of Geophysical Research.

Iverson, R.M., and Denlinger, R.P., in press. Flow of variably fluidized granular masses across 3-D terrain: 1. Coulomb mixture theory, Journal of Geophysical Research.

Future Projects Where Research May Be Used:

Any dams that require flood-frequency analyses for return periods exceeding 1000 years.

Schedule for the Upcoming Fiscal Year:

The budget request for FY01 is for D. O'Connell to incorporate all the modifications to the TrimR2D, SISL3D, and finite-volume software from the work funded in the PHYPL FY00 research program into the paleoflood hydraulic modeling software package. Software modification to the existing paleoflood hydraulic modeling software will occur after changes to TrimR2D, SISL3D, and the finite-volume

software are provided by the external partners. Changes to TrimR2D will be provided first, followed by SISL3D software, and the finite volume software.

Qtr 1. TrimR2D changes: 5 days (O'Connell)
Qtr 2. SISL3D changes and installation : 7 days (O'Connell)
Qtr 3. Finite-volume changes: 5 days (O'Connell)
Qtr 4. Project documentation, manual, and journal manuscript: 5 days (O'Connell)

Schedule and Partnership Contributions to Date (All Years):

FY99:

Dr. Denlinger of the USGS developed the first version of the 2D finite-volume hydraulic modeling software with cost sharing by the USGS. Funded by projects, not PLHYM.

FY00:
Dr. Walters developed TrimR2D for river hydraulics. Dr. Denlinger improved the 2D finite-volume hydraulic modeling software and integrated it for use withTrimR2D under a cost sharing agreement with the USGS.

Dam Safety Research Status Update

Project Title:

Probabilistic Flood Hazard Workshop

Research Problem and Background

The formation of the Probabilistic Flood Hazard Cadre signaled a significant change in the way the Dam Safety Office and the Technical Service Center conduct flood hazard assessments for Dam Safety. The purpose of this workshop is to bring in the world's leading experts on various aspects probabilistic flood hazard estimation to assist with the development of the new Reclamation program.

Abstract of Objective

The purpose of this project is to compile, review, and evaluate current state-of-the-knowledge on probabilistic techniques used in flood hazard assessment. External experts in various aspects of flood hazards will be brought in to Reclamation on an individual basis. It is intended that each person present a USBR Technical Update Lecture (1-2 hours). The Flood Cadre will subsequently meet with them to discuss their research in detail and potential technology transfer to Reclamation.

Principal Investigators:

John England, Dan Levish

Team Members:

Marijo Camrud, Jeanne Klawon, Ralph Klinger, Lex Kamstra

Partners:

See List of Workshop Participants (Attached)

Progress to Date

Nine of the world's foremost experts on probabilistic flood hazard estimation have been part of the flood hazard workshop this past year. The participants are listed in the table below. As part of this process each participant gave an one hour technical update lecture for the TSC. A list of presentations is included in the table below.

Future Projects Where Research May Be Used

The workshop is critical to all aspects of probabilistic extreme flood hazard estimation and therefore impacts numerous Reclamation Dam Safety projects.

Schedule and Partnership Contributions to Date (All Years)

Nine experts were brought to the TSC to give technical update lectures and to meet with the Flood Cadre. From these meetings the future direction for probabilistic flood hazard estimation at Reclamation has been identified

Probabilistic Flood Hazard Cadre (PFHC) Workshop Schedule (PRCBF)

Name	Title/Affiliation	Main Subjects	Technology Update Lecture Title	Dates
Dr. Victor Baker	Professor and Department Head, Hydrology and Water Resources Department, University of Arizona	Paleoflood Hydrology Data and methods inverse problems nonstationarity	Science and Public Policy: A Dysfunctional Relationship?	11/18/1999
Dr. Upmanu Lall	Professor of Civil Engineering, Utah State University	Climate variability non-parametric techniques hydrograph sampling flood frequency	Climate Variability and Flood Frequency	01/26/2000
Dr. Edward Tomlinson	President, Applied Weather Associates, Monument, CO	historical storm investigations hydrometeorological methods	Technical Issues Associated with Site-Specific Probable Maximum Precipitation Studies	02/18/2000
Mr. John Henz	President, Henz Meteorological Services Inc., Denver, CO	recent storm reconstructions frequency of atmospheric components	Extreme Precipitation Event Reconstruction: Innovative Uses of Radar and Lightning Observations	03/17/2000
Dr. Robert Webb	USGS National Research Program, Tucson, AZ - Response of Fluvial Systems to Climatic Change	paleoflood hydrology and hydraulic methods flood frequency with paleoflood data	Climate, Flood Frequency, Flow Regulation, and Riparian Vegetation: An Alternative View of Wetlands in the Southwestern United States	03/20/2000
Dr. Norman Crawford	President, Hydrocomp Inc., Menlo Park, CA	continuous hydrologic modeling model calibration	Modeling Surficial Hydrologic Processes: The Role of the Land	03/27/2000
Dr. James Smith	Professor, Civil and Environmental Engineering, Princeton University	extreme storm hydrometeorology physical mechanisms of largest floods	The Regional Hydrology of Extreme Floods in an Urbanizing Drainage Basin	06/13/2000
Dr. Katherine Hirschboeck	Associate Professor of Climatology, Laboratory of Tree-Ring Research, University of Arizona	flood hydroclimatology, paleoclimate data, dendrochronology	Flood Hydroclimatology and Its Applications in Western United States	06/23/2000
Dr. George Kuczera	Associate Professor, Department of Civil, Surveying and Environmental Engineering, University of Newcastle, Australia	rainfall-runoff modeling hydrologic modeling -model and parameter uncertainty flood frequency	Stochastic Hydroclimatic Models: The Challenge of Inter-Annual Persistence	08/15-18/2000

Dam Safety Research Status Update

Project Title:

Compilation and Review of Stochastic Models

Research Problem and Background

Some form of stochastic rainfall-runoff model is necessary to develop volume estimates for extreme floods. Reclamation has little experience with these types of models for Dam Safety analyses. A review of existing rainfall-runoff models is an important component of incorporating these models into flood hazard analyses.

Abstract of Objective

The purpose of this project is to perform a detailed analysis and review of the stochastic rainfall\runoff models and evaluate their applicability to the Reclamation Dam Safety program objectives.

Principal Investigators:

Marijo Camrud

Team Members:

John England, Jeanne Klawon, Ralph Klinger, Dan Levish

Peer Reviewer(s):

Dr. George Kuczera, University of Newcastle, Dr. Norm Crawford, Hydrocomp, Dr. Ed Tomlinson, Applied Weather Associates, Dr. Upmanu Lall, Columbia University

Partners:

University of Newcastle, Princeton University, University of Minnesota, University of Arizona, Applied Weather Associates

Progress to Date

The four peer reviewers listed above were asked to review the MGS stochastic rainfall-runoff model. Final comments have been received from three of the reviewers and preliminary comments have been received from the fourth. These comments pointed out key research areas for the future including stochastic storm transposition, proposed for FY01 research. A bibliography has also been compiled from the literature on stochastic rainfall runoff models.

Future Projects Where Research May Be Used

Estimates of extreme flood hydrographs are a necessary component for many Reclamation Dam Safety flood hazard analyses. Although there are currently tools in place to estimate flood peak discharge frequency for extreme events, the tools to derive hydrograph shape and volume are still being developed. This project plays a key role in that development and therefore will have wide applicability to numerous Reclamation Dam Safety projects.

Schedule for the Upcoming Fiscal Year

The funding for the upcoming fiscal year will cover the completion of a summary of existing stochastic rainfall-runoff models, the scoping of stochastic storm transposition research, and the development of a final document. It is anticipated that the model summary will be complete in March 2001, the feasibility of stochastic storm transposition will be complete in June 2001, and the summary document will be ready in July 2001.

Schedule, Costs, Partnership Contributions to Date (All Years)

Three of the four peer reviewers have provided comments on the MGS model and the fourth has provided preliminary comments. Through this process future research areas have been identified and incorporated into the FY01 research plan.

SEISMOLOGIC RESEARCH

Dam Safety Research Status Update

Project Title:

Seismic Ground Motions and Arias Intensity

Research Problem and Background:

(1) The seismic responses of soils are complicated by various types of nonlinear amplification related to internal soil deformation (nonlinear damping) and transient pore-pressure responses. The SEIGM project is developing empirical and theoretical tools to estimate seismic responses of soils for seismic hazard assessments. (2) The translation of existing seismic hazard results into appropriate time histories is currently rather *ad hoc*. This project endeavors to develop more robust tools to make this transition.

Abstract of Objective (200 words or less):

(1) Develop methods to estimate the seismic responses of soils. Explicit nonlinear finite-difference codes are being developed and tested to predict ground motion time histories for undrained soil sites. (2) Empirical Arias intensity relations are being developed to provide more relevant and robust seismic loads for deformation and liquifaction triggering analyses. Alternative parametric tools are needed to choose time histories in a more robust fashion. Factors such as peak horizontal acceleration and response spectra are insensitive to critical measures that strongly influence dynamic response.

Principal Investigator:

Jon Ake

Team Members:

Jon Ake and Dan O'Connell

Peer Reviewer(s):

Dan O'Connell

Partners:

Dr. Walt Silva, Pacific Engineering, Drs. Ralph Archuleta, Fabian Bonilla, and Jamison Steidl, University of California, Santa Barbara, Dr. Robert Pyke, Consultant

Progress to Date:

A large number of existing strong-motion recordings have been processed to provide data on Arias Intensity, Acceleration Spectrum Intensity and peak velocity. This includes data from recent large, damaging earthquakes in Taiwan and Turkey. The data base is now ready to be used in the final development of the regression relationships. Algorithms for computing scalar Arias Intensity (AI) as well as Husid Plots of AI (5% and 95% limits) have been developed in-house and are in use at the present time. Funds from this project were also used to develop filtering algorithms to modify empirical time histories in a more robust fashion for use in the dynamic analyses of concrete dams. These tools are also currently being used.

A Nonlinear Soil Response Workshop was convened in Denver June 29-30, 2000 sponsored by the SEIGM and SPVGM projects. Leading experts presented research results and recommendations for approaches to incorporate nonlinear soil responses into ground motion estimation and probabilistic seismic hazard assessment. Drs. Walt Silva of Pacific Engineering, William Joyner of the USGS, Menlo

Park, and Fabian Bonilla and Ralph Archuleta of the Univ. Of California, Santa Barbara each gave presentations. Dave Gillette and Karl Dise participated in the workshop along with Drs. Art Frankel and Steve Hartzell of the USGS. Dr. Silva presented the results of his and Dr. Pyke's latest investigations of modulus reduction curves for various soils and transmitted the modulus reduction data to Reclamation. The principal conclusion of the workshop was that time-dependent pore-pressure variations can strongly modify nonlinear soil responses and substantially change peak responses, frequency content, and duration of strong ground motions for undrained soil sites typical of Reclamation's embankment dams. The SEIGM project paid for Walt Silva's and William Joyner's attendance at the workshop.

Based on the results of the Workshop, a new SEIGM FY00 agreement was established with the Univ. Of California, Santa Barbara group to expand their investigations of the nonlinear responses of undrained soils to test the sensitivity of the output ground motions from the numerical code NOAH to various input parameters to determine which have the greatest influence on the calculated seismic responses. The sensitivity analysis in nonlinear site response will focus on the strength of the material and dilatancy parameters. To provide capabilities to model ground motions from thrust and normal faults they will develop a general purpose P-SV code to study nonlinear wave propagation in a 2D medium that uses the stress-strain rheology developed by Towhata and Ishihara (1985) and Iai et al (1990a, b) that takes into account cyclic mobility in sands.

Future Projects Where Research May Be Used:

B.F. Sisk, O'Neill, Jackson Lake, Contra Loma, and just about any dam or structure founded on soil. Aria Intensity and Acceleration Spectrum Intensity tools will be used on all projects where it is necessary to develop time histories.

Schedule and Partnership Contributions to Date (All Years):

In the coming year it will necessary to begin evaluating the existing data base of liquefaction occurrences. For this task it will be necessary to have the cooperation and involvement of Dave Gillette (D-8313).

In previous years, a substantial amount of Dr. Silva's time has been either donated or covered by existing NEHRP grants. This has been provided under the assumption that peer-reviewed publications will be produced as a result of this work.

Dam Safety Research Status Update

Project Title:

Spatially Varying Ground Motions

Peak ground motions depend on energy radiated by rupturing earthquake faults, the dimensions of fault rupture, the focusing effects of crustal velocity structure, and near-surface velocity structure. The SPVGM project has developed tools and understanding to quantify the influence these factors for seismic hazard assessment.

Task 1: Research Problem and Background:

Peak ground motions are strongly affected by style of faulting. For sites located close to faults, limited empirical data suggests that thrust faults produce much larger peak ground motions for frequencies greater than 1 Hz than strike-slip faults. No physical mechanism has been proposed to explain these observations. Consequently, there is little quantitative basis to account for the frequency-dependence of peak ground motions for strike-slip, thrust, and normal faults.

Task 2: Research Problem and Background:

There is little basis for estimating maximum earthquake magnitudes for segmented faults, particularly for thrust and normal faults. Several M > 7 strike-slip earthquakes in the past 10 years have been produced by multi-segment faults ruptures. A quantitative approach to estimate multi-segment earthquake rupture likelihoods is needed for seismic hazard assessment.

Task 1: Abstract of Objective:

The difference in the geometry of strike-slip directivity versus dip-slip directivity combined with three-dimensional correlated velocity variations (virtually ubiquitous in the western U.S.) probably produces most of the differences between strike-slip and dip-slip directivity for frequencies > 1 Hz. The results of O'Connell (1999) will be extended to provide a quantitative physical explanation of for the frequency-dependence of peak ground motions for strike-slip, thrust, and normal faults and the understanding necessary to account for these variables in probabilistic seismic hazard assessment.

Task 2: Abstract of Objective:

Dynamic rupture simulations by Drs. David Ogelsby and Steven Day (among others) for thrust and strike-slip faults suggest that fault segmentation provides a strong barrier for multi-segment fault ruptures in some cases. It appears that the ability of multiple fault segments to rupture together in a single earthquake is related to the separation distance, segmentation geometry, and tectonic stress orientations. These variables can be directly observed in the field for strike-slip faults and inferred from geophysical data for dip-slip faults. The focus of this task is to quantify how these variable influence multi-segment rupture probabilities for both strike-slip and thrust faults using dynamic rupture simulations.

Principal Investigator:

Dan O'Connell

Peer Reviewer(s):

Jon Ake

Partners:

Drs. Steven Day and David Ogelsby, San Diego State University, Dr. Robert Graves, Woodward-Clyde Pasadena, CA, Dr. Dudley J. Andrews, USGS, Menlo Park, and Drs. Ralph Archuleta and Fabian Bonilla of the Univ. Of California, Santa Barbara.

Progress to Date:

Dr. Dudley J. Andrews of the USGS has provided his finite-difference dynamic rupture code modified to include four fault segments in a single simulation. This code has been compiled and installed on Reclamation computers. Dr. Ogelsby of San Diego State Univ. has performed dynamic rupture simulations using a modified version of the DYNA3D finite-element code for blind thrust rupture geometries corresponding to faults near Monticello, Stony Gorge, and East Park Dams that suggest that multi-segment thrust-faulting earthquakes are highly unlikely near these dams, providing a strong basis for assigning maximum earthquakes for seismic hazard assessments for these dams. Dr. Ogelsby's modified version of DYNA3D has been installed on Reclamation computers and Dr. Ogelsby has traveled to Denver to instruct Reclamation on the use of DYNA3D for earthquake rupture simulations. Dr. Robert Graves performed ground motion simulations to assess the influence of complex three-dimensional velocity structure near B.F. Sisk and O'Neill Dams on peak ground motions associated with rupture directivity of strike-slip earthquakes on the Ortigalita fault. Task 2 work will be completed under a FY00 contract.

Future Projects Where Research May Be Used:

B.F. Sisk, O'Neill, Jackson Lake, Contra Loma, Stony Gorge, and East Park Dams, and any other Reclamation dams located adjacent to strike-slip, thrust, or normal faults. In particular, Task 1 may show that rupture directivity and peak accelerations for frequencies > 1 Hz associated with M ~ 7 earthquakes on the Ortigalita fault may be substantially lower for B.F. Sisk and O'Neill Dams than previous estimates.

Schedule for the Upcoming Fiscal Year:

D. O'Connell begins investigations:	Nov 15, 2000.
Investigations completed:	March 31, 2001.
Peer Review completed:	April 30, 2001.
Paper submitted for publication:	May 15, 2001.

Schedule and Partnership Contributions to Date (All Years):

Drs. Ogelsby and Day have begun the investigations identified in Task 2 under a FY00 Woodward-Clyde contract with SPVGM funds. The thrust-faulting simulations are being performed first to support finalizing the probabilistic seismic hazard assessments for Stony Gorge and East Parks Dams. These simulations will be completed by September 30, 2000. Dynamic rupture simulations for segmented strike-slip faulting relevant to B.F. Sisk and O'Neill Dams will commence in November 2000 and extend into March of 2001.
FY00 investigations by Drs. Ogelsby and Day were also supported by the National Earthquake Hazards Reduction Program (NEHRP).

Dr. Graves of Woodward-Clyde will assist in Task 1 using the funds remaining from the FY00 delivery order to calculate synthetic seismograms for strike-slip faulting geometries with three-dimensional velocity models that include correlated-random velocity variations near B.F. Sisk and O'Neill Dams. Work will commence in September, 2000 and extend to December 2000.

Dr. Andrews of the USGS delivered finite-difference dynamic rupture modeling software to Reclamation

with documentation and performed dyanmic rupture calculations using a rupture model provided by Reclamation.

Drs. Ralph Archuleta and Fabian Bonilla the UCSB nonlinear soil code (NOAH) to calculate the ground motion responses at the toe of O'Neill Dam to two strong ground motion inputs obtained from the 1995 M 6.9 Kobe and 1983 M 6.5 Coalinga earthquakes. The results were presented at a Reclamation workshop on nonlinear soil response held in Denver June 29-30, 2000. Their results showed that including time-dependent pore-pressure responses substantially changed peak accelerations and durations relative to equivalent linear approaches. Their NOAH code successfully reproduced soil ground motion time-histories and spectra from several undrained soil sites that experienced strong ground shaking. Continuation of this research has been transferred to the SEIGM project.

FY99

Paper by D. O'Connell containing the results of the first year funding of SPVGM was published in the March 27, 1999 issue of Science. These results were used to show that peak spectral responses for Monticello Dam are likely to be 2/3 of values estimated from empirical attenuation relations.

CONSEQUENCES RESEARCH

Dam Safety Research Status Update

Project Title:

Estimating the consequences of dam failure.

Research Problem and Background:

Reclamation published, "A Procedure for Estimating Loss of Life Caused by Dam Failure," DSO-99-06, in September 1999. This current research focuses on the loss of life that would result from spillway gate failure or mis-operation.

Abstract of Objective (200 words or less):

The failure or mis-operation of a spillway gate or gates has the potential for causing injury and loss of life as well as property damage. The potential for loss is dependent on many factors. Some of these factors might include characteristics of the dam, reservoir and spillway. Also important would be the hydraulic characteristics of the channel and floodplain downstream from the dam as well as the temporary and permanent uses of areas subject to inadvertent spillway releases.

The goal of this research will be a ranking system whereby the relative danger caused by failure or misoperation will be established. It is anticipated that the failure of some gates would cause little or no loss whereas others might cause significant loss. The reservoir level at the time of gate failure or misoperation will be an integral part of the ranking system.

Principal Investigator:

Wayne J. Graham, P.E.

Team Members:

There are no officially designated team members. However, draft thoughts and reports are shared with Reclamation staff having an interest or need-to-know. Comments from these people are used to improve the quality of the research.

Peer Reviewer(s):

Mr. James Melena and possibly others.

Partners:

None at this time.

Progress to Date:

In June 2000, a draft report was sent to several engineers and decision makers within Reclamation. The report was titled: "Losses Caused by Spillway Gate Failure or Mis-operation." Some of the reviewers identified additional case studies that should be evaluated. These cases will be evaluated and then an updated version of the report will be sent out for review and comment.

Future Projects Where Research May Be Used:

The final report will enable people both inside and outside of Reclamation to estimate the consequences associated with the failure of 1 or more spillway gates. An estimate of the losses (human lives) caused by spillway gate failure is needed in order to conduct of risk-based decision making.

Schedule, Costs, Partnership Contributions to Date (All Years):

Estimating the consequences of gate failure began in fiscal year 2000. Work undertaken in years before fy 2000 was devoted to completing DSO-99-06.

Prepared by Wayne J. Graham
August 8, 2000